A COMPARISON BETWEEN A SINGLE AND A DOUBLE TUNED HYBRID POWER FILTER UNDER POWER QUALITY ANALYSIS

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***Abstract*—This article presents a comparative analysis between two hybrid active power filters, a single tuned hybrid active power filter (STHF) and a double tuned hybrid active power filter (DTHF). This comparative study focused to analyze the power filters performance under the following characteristics: the total harmonic distortion, power factor correction and the power processed by the converter. The instantaneous power theory was used to implement the control of the active power filters. It was also used the Multiple Second Order Generalized Integrator-Frequency Locked Loop (MSOGI-FLL) circuit in order to improve the selectivity algorithm of the filter active. The STHF and DTHF topology will be discussed as well as the implemented control strategy. The simulation results were obtained using the PSCAD/EMTDC software that was used to build the simulation models.**

***Keywords*—Power Quality, Active Filter, Hybrid Filter, Power Conditioner.**

I. INTRODUCTION

The non-linear loads yield harmonic pollution into the power grid. The spread of this kind of load is really a problem for the power quality because the harmonics increase the losses in the distribution system and causes voltage distortions. The Shunt Passive Filter has traditionally been used to mitigate distorted current, mainly due to their lower cost and minimum maintenance requirements, but it has a lot of drawbacks such the possibility of resonance with the power system impedance and bad performance under the variation of this impedance. Active filters overcome the drawbacks of passive filters. The objective of an active filter is generate compensation currents to mitigate the harmonic currents demanded by the nonlinear load. However, they require a large power rating converter in order to realize this function [1]. Another option to improve the power quality in a system with nonlinear load is the application of a Hybrid Active Power Filter (HAPF). A hybrid power filter is formed by a combination of a passive power filter and an active power filter. It usually overcomes the drawbacks of the passive and active filter. A HAPF could be implemented using the four-wire or three-wire topology. The Figure 1 shows a regular three-wire single-tuned hybrid power filter [2].

Then aim of this work is to compare two topologies of HAPF proposed in [3] and [4], showed in Fig. 2 and Fig. 3, respectively. The first one is a single tuned four-wire hybrid power filter (STHF) and the second one is a double tuned four-wire hybrid active power filter (DTHF). For this study a non-linear load with same characteristics was connected to each HAPF and the results were analyzed. The control strategy of these filters is based on the Instantaneous Power Theory that was formally presented in [5]. It was used a very powerful multiple frequency synchronization circuit called MSOGI-FLL to tune harmonic frequencies not tuned by the passive filter. The Simulation results were obtained using PSCAD/EMTDC model and will be presented in order to comprove the idea behind that work.

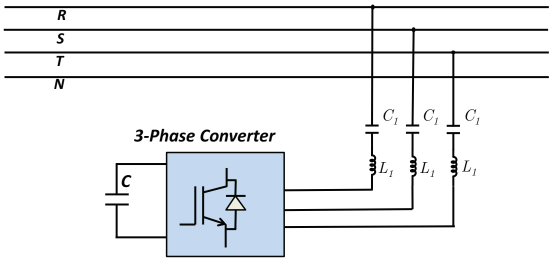

Fig. 1. Series combination of parallel-passive and parallel-active filters.

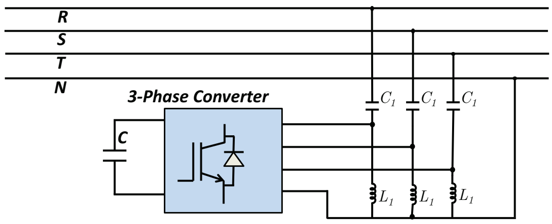

Fig. 2. The single tuned hybrid active power filter.

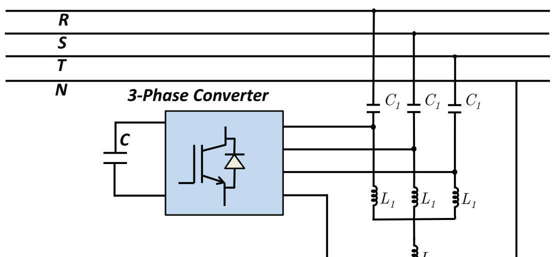

Fig. 3. The double tuned hybrid active power filter.

The paper is organized as follows. The Section II presents a brief overview about pq theory and addresses the need for elimination of oscillating power in the electric system. The section III shows the filters topology. The control strategy is detailed in section IV. A case study is addressed in section V. The simulations results and the conclusion are respectively presented in sections VI and VII, respectively.

II. PQ THEORY

The instantaneous power theory handles with two approaches. The first one is based on Clarke transformation and the second one is developed directly in the abc system. The Clarke transformation is a matrix operation which changes a three axes three-phases voltage (or current) system in a stationary three orthogonal reference frame ($\alpha\beta 0$). One advantage of the Clarke transformation is the easy way to obtain the zero sequence component. According to the pq Theory the instantaneous active, reactive and zero sequence power each of them have both average and oscillating parts. They can be written as

$$p = \bar{p} + \tilde{p}, \quad (1)$$

$$q = \bar{q} + \tilde{q}, \quad (2)$$

$$p_o = \bar{p_o} + \tilde{p_o}. \quad (3)$$

The harmonics are responsible for come up the oscillating powers that are harmful for the electrical system. A hybrid filter is able to mitigate the harmonics of the system and so on the oscillating powers.

III. DESCRIPTION ABOUT THE STUDIED TOPOLOGIES

The purpose of this paper is to analyze and compare two Hybrids Power Filters topologies. One of them is a single tuned three-phase four-wire hybrid active power filter (STHF) shown in Fig. 2, and the other one is a double tuned hybrid power filter (DTHF) and it is showed in Fig. 3. It was used the combination of the b-shaped one-branch and the b-shaped L-type passive filters structures to build the DTHF topology [6]. The structure has a set of three inductors L_1 and a single inductor L_n installed in neutral of the system. The inductor L_n presents a resonant frequency for the zero sequence components [7]. The passive filter could mitigate two harmonic frequencies and the active filter could mitigate the others harmonics presented in the nonlinear loads currents. In this work the passive filter was tuned to eliminate the 3^{th} and the 5^{th} harmonics, and the aim of the active filter is to mitigate the 7^{th}, 9^{th}, 11^{th}, 13^{th}, 15^{th} and the 19^{th} harmonic, exactly as it was done in the work [4].

1) The DTHF - The passive filter was tuned to eliminate the two most dominant harmonics. The capacitance C_1 and the inductance L_1 must be designed to eliminate the second more dominant harmonic. The passive components formed by C_1, L_1 and the inductance L_n are supposed to mitigate the first most dominant harmonic. The capacitance C_1 and the inductance L_1 make up a L_1C_1 passive filter tuned to fifth harmonic, and it's resonance frequency is written as

$$f_5 = \frac{1}{2\pi\sqrt{L_1C_1}}. \quad (4)$$

The group composed by C_1, L_1 and L_n formed the $L_{1n}C_1$ passive filter that is tuned to third harmonic, and it's resonance frequency is given by

$$f_3 = \frac{1}{2\pi\sqrt{(L_1 + 3L_n)C_1}}. \quad (5)$$

2) The STHF - According to [8] the STHF is able to reduce the converter processed power by 10% in relation to a pure active power filter and the structure depicted in Fig. 1 can reduce only 16%. In both STHF and DTHF topologies the reactive current is determined by the capacitor of the passive filter and it is divided among the inductors and the converter. The work presented in [8] addressed that if the converter is modeled as voltage source then it is necessary a greater inductance value in the input of the converser in order to reduce the reactive current. However if the converser is modeled as current source it will impose a fundamental current behavior through the inductors of the passive filter. The converter modeled as a current source processes lower power than the other one modeled as voltage source. In this paper the converter was modeled as a current source.

The study presented in [9] concluded that the STHF tuned at 5^{th} harmonic has lower processed power by the active filter than topologies showed in Fig. 1. But it was also observed that a small parcel of power in the converter implies in a bulky to a dc-link capacitor. The resonance frequency for the STHF is also given by (4).

IV. CONTROL STRATEGY

The main objective of the control strategy is to mitigate the aforementioned harmonic frequencies not filtered by the passive filter. The Fig. 4 shows the block diagram of the control strategy applied to filter converter. The subscripts abc and $\alpha\beta$ mean the abc and the stationary $\alpha\beta$ coordinate systems respectively. The superscript $(*)$ and the over-bar $(-)$ mean reference and average values respectively. v_s, v_{s1}, v_{sh}, i_s, i_f, p and q are system voltage, fundamental system voltage, harmonic system voltages, source current, compensation current, instantaneous active and imaginary power, respectively. The numbers near the lines indicates the quantity of signal that enters or exit the blocks.

The control strategy is based in the instantaneous power theory. The control circuit collects the voltages of the system and changes them to a stationary orthogonal ($\alpha\beta$) reference frame. A very powerful multiple frequency synchronization circuit called Multiple Second Order Generalized Integrator-Frequency Locked Loop (MSOGI-FLL) was used to tune the fundamental frequency and the harmonics of the system voltage not tuned by the passive filter. The MSOGI-FLL was formally presented in [10]. It is a group of n selective and adaptive filters tuned at multiple desired frequencies, and it is composed by a Frequency-Locked Loop (FLL) and n Dual Second Order Generalized Integrator (DSOGI), both presented in [11].

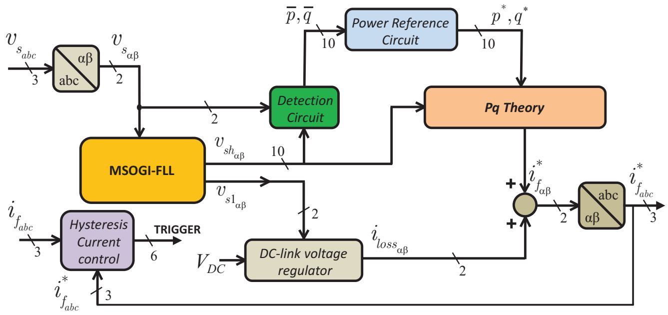

Fig. 4. Control block diagram of the active filter.

The instantaneous active and reactive power have average and oscillating components ($p = \bar{p} + \tilde{p}$). After calculating the instantaneous power and using a low pass filter, the detection circuit separates the average power portion for each harmonic frequency. With the instantaneous power reference it is easy to obtain the reference compensation currents, given by (6). These currents are input for the hysteresis control , which generates the trigger signals to the switches of the converter. It is worth to highlight that the dc-link regulator provides the losses components ($i_{loss\alpha\beta}$) for the compensation currents. The currents losses include the compensation for the losses in the switches of the converter. It is necessary to achieve a low ripple dc-link voltage.

$$\begin{bmatrix} i_{h\alpha}^{*} \\ i_{h\beta}^{*} \end{bmatrix} = \frac{1}{v_{s\alpha}^{2} + v_{s\beta}^{2}} \begin{bmatrix} v_{s\alpha} & v_{s\beta} \\ v_{s\beta} & -v_{s\alpha} \end{bmatrix} \begin{bmatrix} p_{h}^{*} \\ q_{h}^{*} \end{bmatrix}. \quad (6)$$

V. CASE STUDY

It was compared the harmonic mitigate capability and the power processed in the active power filters for the both topologies (STHF and DTHF). The software PSCAD/EMTDC was used as an assessment tool.

The active filter of the DTHF topology does not need to tune the 3^{th} because the passive filter does it. However the active filter of the STHF topology needs to tune the 3^{th} because its passive filter is not able to do it. The hybrid active power filter and the system considered in this work is depicted in Fig. 5. The three-phase system is balanced with linear and non-linear loads (3 single-phase converters and 1 three-phase converter). Producing harmonics symmetric and asymmetric besides phase shift between current and voltage of the system. It's important to note that for STHF the inductor L_2 of Fig. 5 does not exist.

VI. SIMULATION RESULTS

The simulation results is divided in three intervals. The first interval consists in the operation without filter, that starts at time $t = 0s$ and ends at time $t = 1.5s$. The second interval is characterized by the insertion of the passive filter. It starts at $t = 1.5s$ and stays until $t = 3s$. The last interval starts when the active filter is connected at $t = 3s$. The simulation was carried out using the PSCAD/EMTDC and the simulation parameters are shown in Table I. The simulation results are shown in Figs. 6-18.

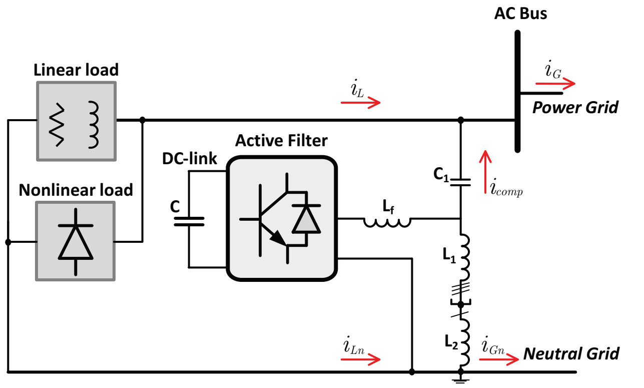

Fig. 5. Simulated power system.

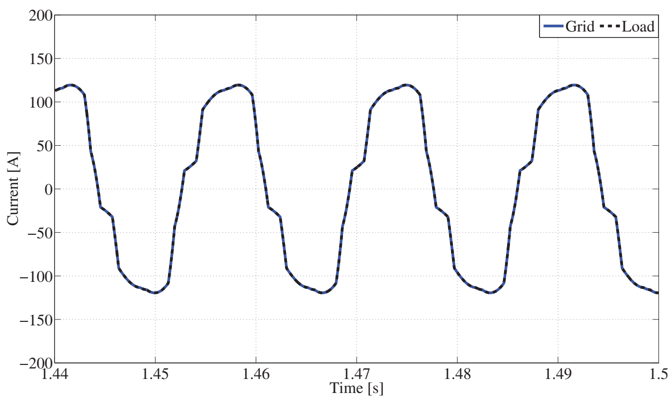

Fig. 6. Load and grid currents.

Figure 6 shows the nonlinear load current in the first interval. In this interval there is no harmonic compensation. Thus, the grid current presents the same behavior of the load current.

Figure 7 shows the load and grid currents when the STHF is connected and Fig. 8 shows the load and grid currents when the DTHF is connected. It can be seen that the DTHF operation produces a lower notch characteristic in the current behavior for this interval. This occurs because the DTHF is able to tune the 3^{th} harmonic.

Figures 9 and 10 shows the load and grid current at the last interval. In this interval the active filter is connected, i.e, the

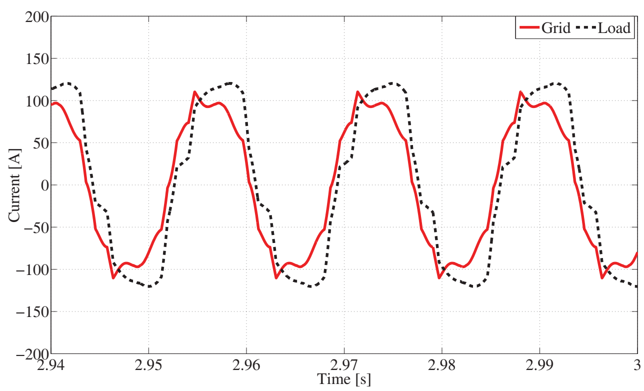

Fig. 7. Load and grid currents in the second interval (STHF).

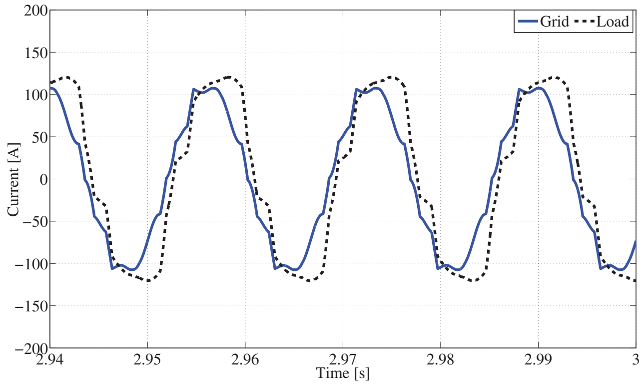

Fig. 8. Load and grid currents in the second interval (DTHF).

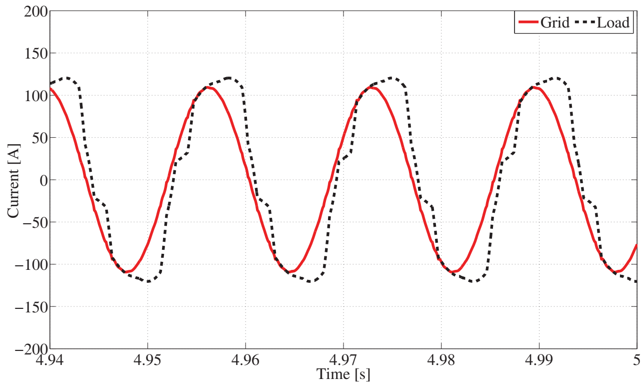

Fig. 9. Load and grid currents in the third interval (STHF).

hybrid filter is in operation. The Figs. 9 and 10 are related with the STHF and the DTHF, respectively. It can be seen that in both topologies achieved a great harmonic mitigation.

Figures 11-15 shows the neutral current on the load side and on the grid side for the same three intervals. Figures 12 and 13 indicates the second interval operation for the STHF and DTHF, respectively. Figures 14 and 15 depicts the last interval operation for the STHF and the DTHF, respectively.

The total harmonic distortion of the grid current (THDi) and voltage(THDv) during all simulation intervals are highlight in Figs. 16 and 17. These figures depicts the performance of each filter performance individually. They also

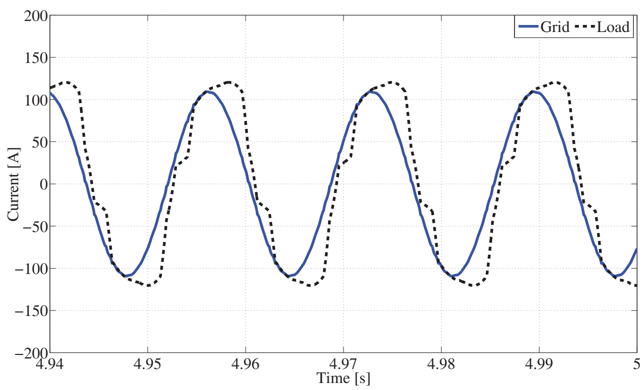

Fig. 10. Load and grid currents in the third interval (DTHF).

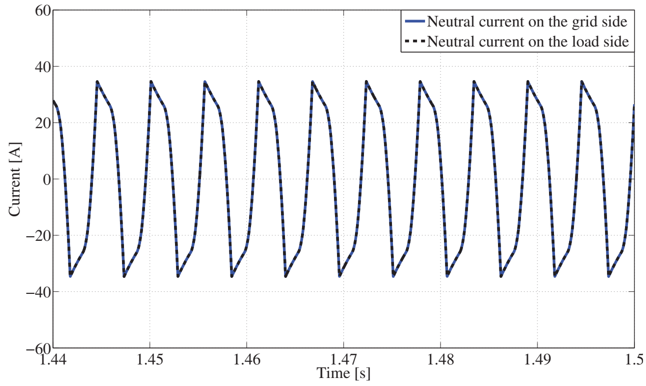

Fig. 11. Load and grid neutral currents in the first interval.

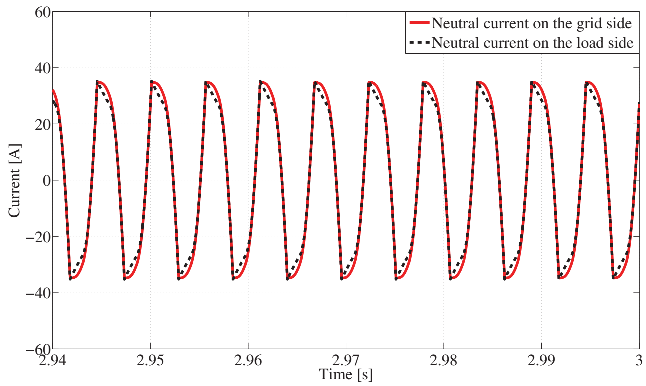

Fig. 12. Load and grid neutral currents in the second interval (STHF).

emphasize the poor power quality of grid currents under the operation without the power filters.

The demanded power from the load was 34,041.50 kVA. That is very interesting because if we compare the hybrid filter power (see Fig. 18) with the load power, we'll note that that relationship is very low.

Figure 19 shows the power factor on the low-voltage side for the system simulated. It's possible to observe that the power factor is practically the same for both hybrid filter topologies.

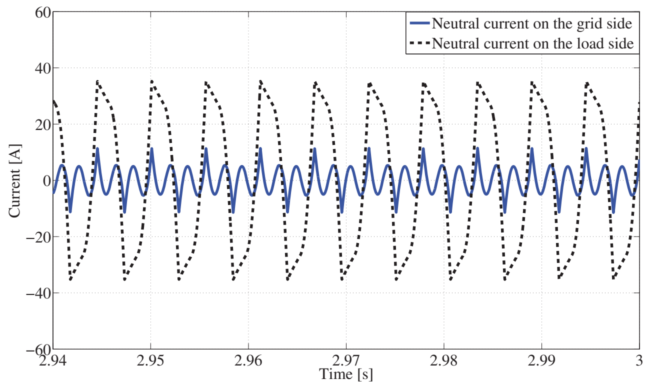

Fig. 13. Load and grid neutral currents in the second interval (DTHF).

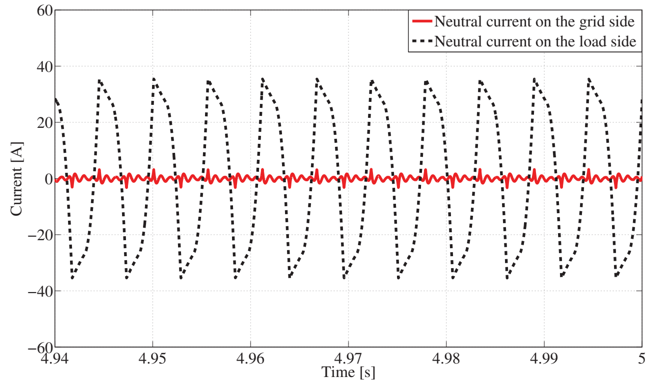

Fig. 14. Load and grid neutral currents in the third interval (STHF).

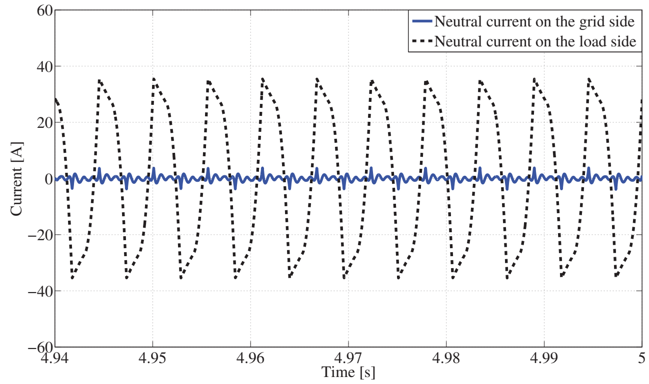

Fig. 15. Load and grid neutral currents in the third interval (DTHF).

Figure 18 compares the active and reactive power processed by converters with DTHF and STHF topologies. Considering the same apparent output power specification of both filters, it could be seen that DTHF topology presented a relevant active power reduction compared to STHF topology.

VII. CONCLUSION

This paper compared the performance between two hybrid power filters named a single tuned hybrid active power filter (STHF), and a double tuned hybrid active power filter (DTHF). It could be seen in the simulations results that both filters have a good performance to correct the power

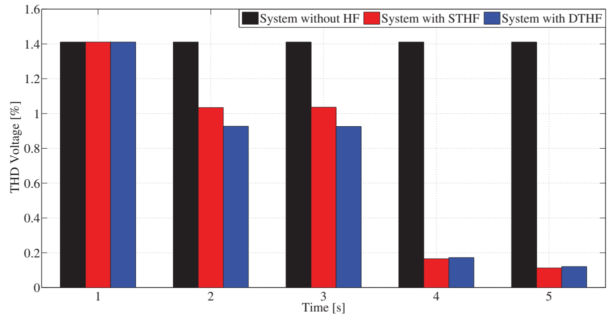

Fig. 17. Total harmonic distortion of the grid voltage.

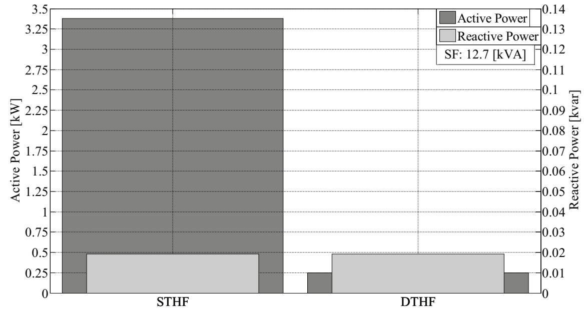

Fig. 18. Converter active and reactive power, total power of the hybrid filter (SF).

factor and compensate harmonic distortions. The STHF was slightly better than DTHF in this characteristics and STFH has also more simple construction. However, the DTHF topology could mitigate the 3^{th} harmonic and STFH could not do it. The active power processed by DTFH is lower than the active power processed by STHF. This result revealed a great advantage of DTHF compared to the STHF, which was always considered one of the best structures for harmonic filtering. The DTHF topology also provides neutral current reduction better than STHF, considering only passive filter operation.

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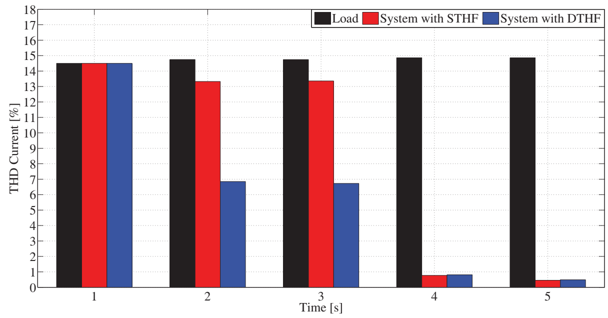

Fig. 16. Total harmonic distortion of the grid and load current.

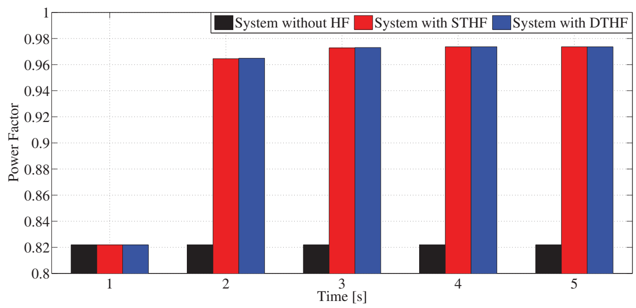

Fig. 19. Power factor on the low-voltage side.

TABLE I
Simulation Parameters.

Parameters	Values
Line to line voltage	220 V
Frequency	600 Hz
Power factor of the system	0.82
THD of the current	14.5 %
THD of the current	1.41 %
RL linear load	3.5 kVA
Rectifier full wave single phase	14.42kVA
Six pulse bridge rectifier	14.86 kVA
Capacitor C_1	670 μF
Inductor L_1	411.5μH
Inductor L_2	244μH

under non-ideal source and load conditions. In *Power Energy Society General Meeting, 2009. PES '09. IEEE*, pages 1–6, 2009.

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